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Dispersion of Frequencies in the Omega Navigation System

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ABSTRACT

It has been proposed to solve the lane identification problem in the Omega navigation system by the transmission of signals at two or more frequencies to produce beat frequencies. A frequency of 13.6 kiloHertz (kHz) will be used with the basic 10.2 kHz transmissions to obtain a three-to-one increase in the width of the ambiguities. The phase velocities of waves at 10.2 kHz and 13.6 kHz are not the same, so a four-to-three relationship of wave lengths will not exist and correction factors will be required to obtain lane identification.

Observations were made in an aircraft flying from the transmitting stations out to ranges of 4000 miles. The results show that calculated differences in velocity of propagation will be accurate enough to obtain reliable lane identification. The necessary corrections could be provided for the navigator in the form of simple tables.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem 54R04-11

BUSHIPS Project SS 161-001-6154

INTRODUCTION

The basic frequency in the Omega navigation system is 10.2 kiloHertz (kHz); therefore, a line-of-position (l-o-p) will have an approximate eight nautical mile ambiguity on the baseline. The navigator can resolve the ambiguity in several ways, one being to set the receiver to the correct lane number at a known point and then the correct lane number will be indicated automatically as the receiver moves through an operating area. If the signal or power to the receiver is lost, the correct lane number can be recovered by dead reckoning or by other means that the navigator may have at his disposal.

The zone of ambiguity can be increased by the transmission of additional signals at different frequencies and using the beat frequency (reference (a)). This report is concerned with the use of 13.6 kHz in conjunction with the basic Omega frequency of 10.2 kHz.

If 13.6 kHz is used with 10.2 kHz, a beat frequency of 3.4 kHz is obtained. This frequency is one-third the basic Omega frequency; and if the velocities of propagation are the same, a moiré pattern will be produced in which every third zero phase point of the 10.2 kHz signal will coincide with every fourth zero phase point of the 13.6 kHz signal (figure 1). Thus, the zone of ambiguity has been increased by a factor of three. The use of other frequencies can be used to produce other beat frequencies and further increase the width of the ambiguous zones.

The velocity of propagation at 10.2 kHz and 13.6 kHz is not the same, so in actual practice a simple three-to-four pattern as shown in figure 1 will not be obtained. The following equation developed by Watt (reference (a)) shows the phase velocity as a function of frequency.

Equation 1

$$\frac{V_p}{V_o} = 1 - 0.36\, h/a + \left[(2\pi n - \phi_g - \phi_1)\frac{V_o}{4\pi\sqrt{2\pi h}}\right]^2$$

h = effective height of ionosphere at 10.2 kHz

day height - 69.5 kilometers (km)
night height - 86.5 km

At 13.6 kHz

day height - 70.5 km
night height - 87.0 km

a = radius of earth $\approx 6.4 \times 10^6$ meters

ϕ_g and ϕ_i = ground and ionosphere reflection phase lag coefficients (radians)

V_p = phase velocity (meters per second)

V_o = velocity of light

f = frequency in Hertz

n = propagation mode

There are other methods for the calculation of phase velocity but since what is desired in this case is the difference in phase velocity this method appeared as satisfactory as any.

The values of V_p/V_o obtained were as follows:

DAYTIME - Sea Water

1.0026 for 10.2 kHz - eastward
0.9996 for 13.6 kHz - eastward
1.0033 for 10.2 kHz - westward
1.0000 for 13.6 kHz - westward

DAYTIME - Land

1.0023 for 10.2 kHz - eastward
0.9994 for 13.6 kHz - eastward
1.0030 for 10.2 kHz - westward
0.9998 for 13.6 kHz - westward

NIGHTTIME - Sea Water

0.9991 for 10.2 kHz - eastward
0.9973 for 13.6 kHz - eastward
0.9996 for 10.2 kHz - westward
0.9976 for 13.6 kHz - westward

NIGHTTIME - Land

0.9988 for 10.2 kHz - eastward
0.9971 for 13.6 kHz - eastward
0.9992 for 10.2 kHz - westward
0.9974 for 13.6 kHz - westward

While these values may be somewhat different than those that will be used in the charting of the system it is the differences in the velocities that are of interest here and it is expected that errors in the calculated differences should be negligible.

The result of this difference in velocity is shown in figure 2 which is a plot of the difference as referred to wave lengths of 10.2 kHz or lanes on a radial basis. It can be seen that after approximately 100 lanes (wave lengths) at 10.2 kHz have been traversed a difference of one-third of a coarse lane will be accumulated. This corresponds to an error of one wave length at 10.2 kHz with reference to the transmitter. On a hyperbolic grid this would be an indicated 200 l-o-p on the baseline. This curve is based on eastward propagation over sea water during the daytime.

METHOD OF MEASUREMENT

An ITT Federal Laboratories type AN/URN-18(XN-1) Omega monitor receiver was modified by changing the gear head in the servo motors from a ratio of 22325:1 to 4143:1. This enabled the equipment to track at speeds of 200 knots with a lag error of less than two CECS. One CEC is equal to 0.01 wave length.

An adaptor was developed at the U. S. Naval Research Laboratory to permit the AN/URN-18 or AN/WRN-2(XN-1) equipments to simultaneously receive and record information from 10.2 kHz and 13.6 kHz signals. This equipment and a frequency standard manufactured by Sulzer Laboratories were installed in a type EC-121K aircraft (BUNO 135753).

The method of measurement was to fly away from (or toward) an Omega station and count the number of wave lengths at each frequency. This is basically what is done in multiple-rho Omega. The counting is accomplished by comparing the phase of each signal with the frequency standard and recording the results on a strip-chart recorder.

The first investigation was conducted over the Atlantic Ocean using signals from the Forestport transmitter. A flight from Patuxent Naval Air Station to Mildenhall Air Force Base, England, was made. Stops were made at the Naval Air Station, Argentia, Newfoundland, and Keflavik, Iceland, going over and at Lajes Air Force Base, Azores, and Kindley Air Force Base, Bermuda, on the return trip. The trip was planned in this way to have virtually all over-water daylight paths. The maximum speed of the aircraft and the tracking ability of the equipment made it impossible to make the trip in one daylight flight.

The signals from the Forestport station were the only ones that could be used because the attenuation at the Greenland icecap made the signals from Haiku unusable over much of the trip and because only one frequency was being transmitted from Criggion, Wales.

A second trip was made to Hickham Air Force Base, Hawaii, with a stop in California at the Naval Air Station, Moffett Field, on the outbound trip and at the North Island Naval Air Station on the return trip. Data was obtained from the Haiku, Hawaii, and the Forestport, New York, Omega stations. These data gave information on westward and overland propagation. It was not possible to have all daylight conditions on this trip. Therefore, the calculations were made for nighttime conditions when applicable.

DATA ANALYSIS

Figure 3 is a plot of the data obtained on the trip to Mildenhall. The aircraft was flown close to the Forestport station and this point was used as the starting point. Since only daylight paths were involved the data were referenced to take-off to the same reading as was obtained on landing at each stop. The variations shown for approximately the first 40 wave lengths (620 miles) are caused by mode interference. The observed data follow the calculated values very closely until the aircraft was about 115 wave lengths from the station. Here there is an unexplained deviation from the calculated value. This occurred at 1800Z so night-to-day transition effects can be ruled out. The variation as the aircraft got further from the station was due to the poor signal-to-noise ratio. The receiver did not use aided tracking and, therefore, a wider bandwidth than is used in the aircraft receivers was required.

However, the data show that the calculated velocity difference was close enough to the observed values to provide lane identification, with the exception of the close-in areas and where the signal strengths were marginal.

Similar data were obtained on the return trip (figure 4). These again show that the computed velocity difference would be accurate enough to provide lane resolution. Slightly better results were obtained in the fringe area of the system because of lower noise.

Figures 5, 6, 7 and 8 show results obtained on the westward trip using both the Haiku station and the Forestport station. The propagation paths are more involved than those on the trip to Mildenhall. Long overland paths existed and it was not possible to make the flights so no transition or nighttime periods would exist. The

calculated curves were, therefore, plotted according to the existing conditions; i.e., day or night, land or sea. The take-off times were under conditions of all-daylight paths, while the time of landing was under conditions of nighttime propagation. Therefore, the data at take-off from Moffett Field and North Island Naval Air Station do not show the same reading as was obtained on landing, as a correction was put in for the diurnal variation.

The same variations due to mode interference again were obtained for approximately the first 50 wave lengths as was seen on the trip to Mildenhall.

CONCLUSIONS

The data show that the calculated difference in the velocity of propagation will be accurate enough to provide lane identification correction factors. Improved results can be obtained for transition periods after more experience has been obtained in choosing the constants used in the calculations. The marginal operation of the equipment at extreme ranges was because the receiver did not use rate-aiding and, therefore, a wider bandwidth was required.

FUTURE PLANS

Continued studies and investigations will be made using 11-1/3 kHz signals and a flight will be made into the Arctic areas.

Investigations will be made to determine the effect of diurnal variations on lane identification at the various Omega frequencies.

REFERENCE

(a) "Omega - A World-Wide Navigation System," System Specification and Implementation by J. A. Pierce, W. Palmer, A. D. Watt and R. H. Woodward, published by Pickard and Burns Electronics, P and B Publication No. 886, dated 1 June 1964.

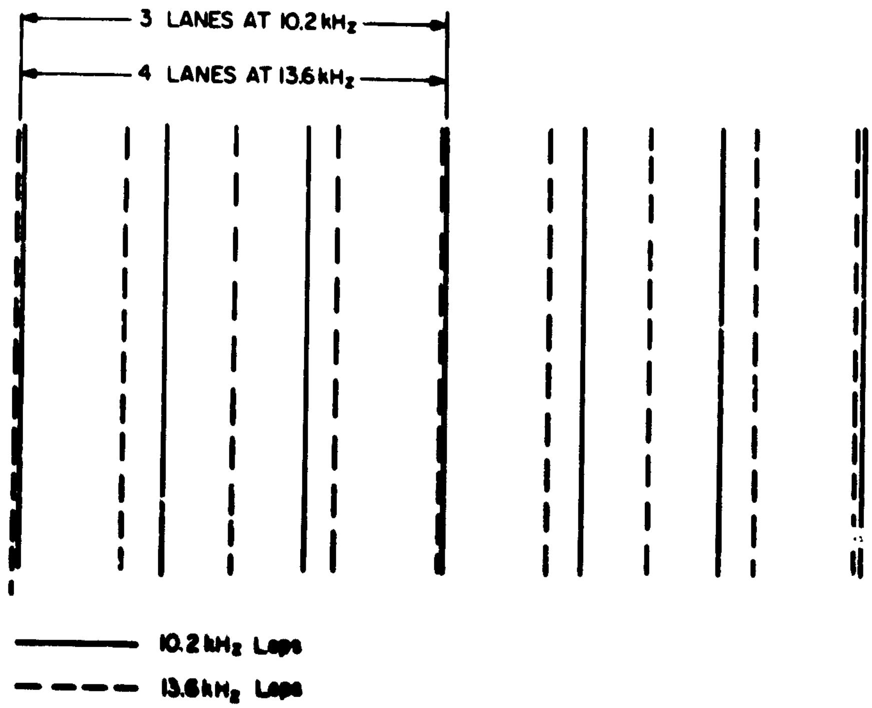


Fig. 1 - Lane identification moire pattern

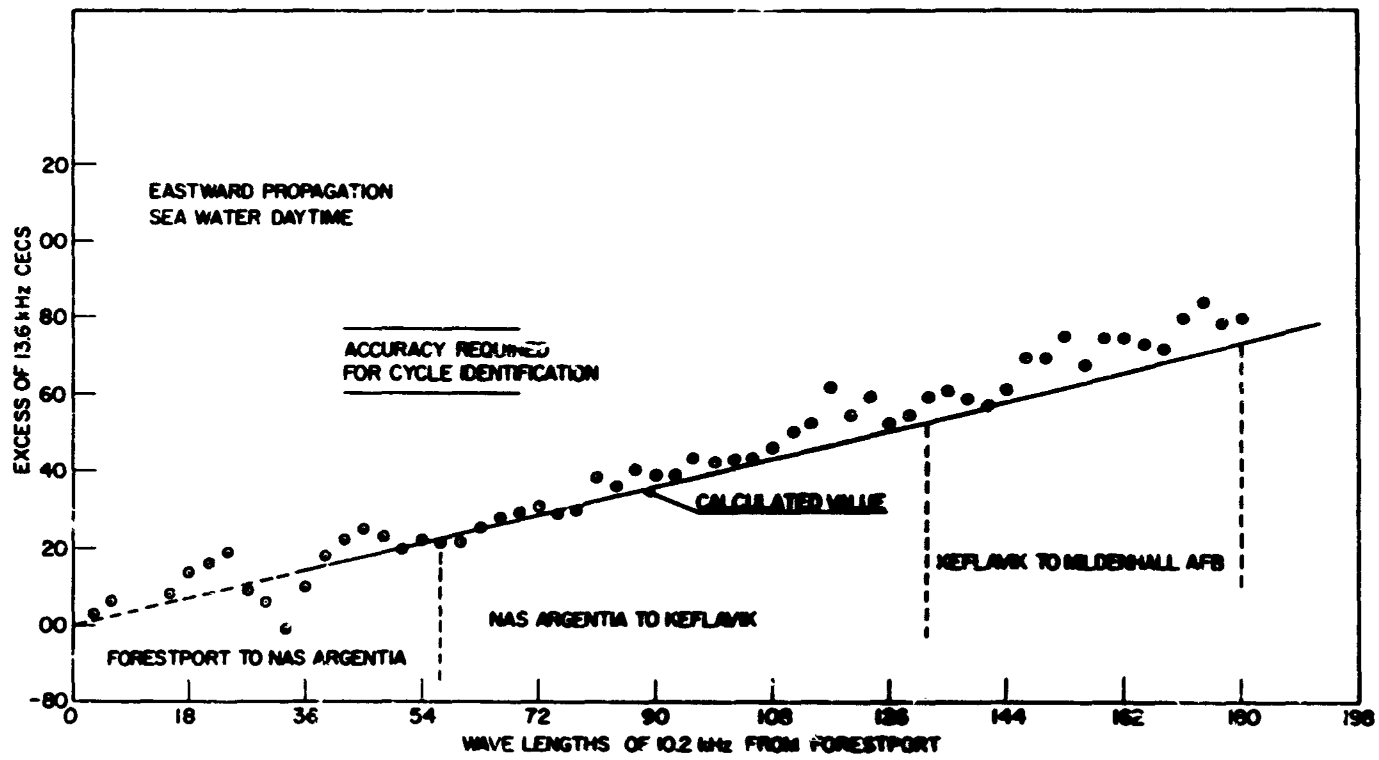


Fig. 3 - Dispersion between 10.2 kH_z and 13.6 kH_z observed on signals from Forestport

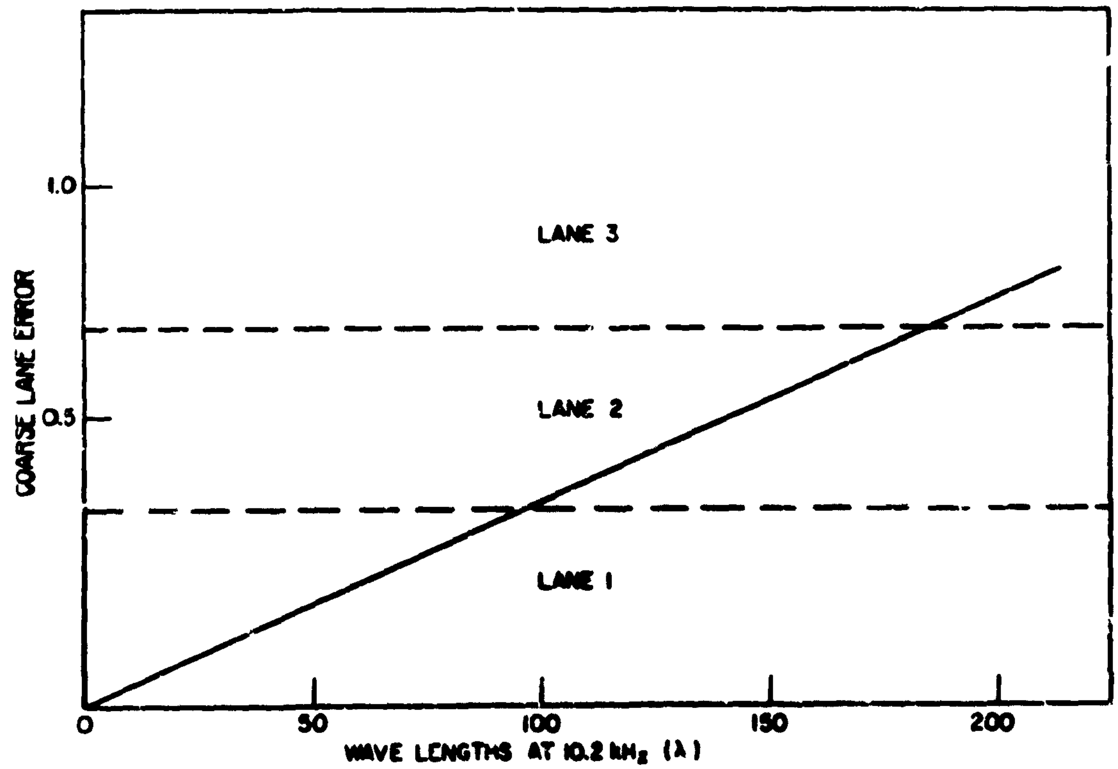
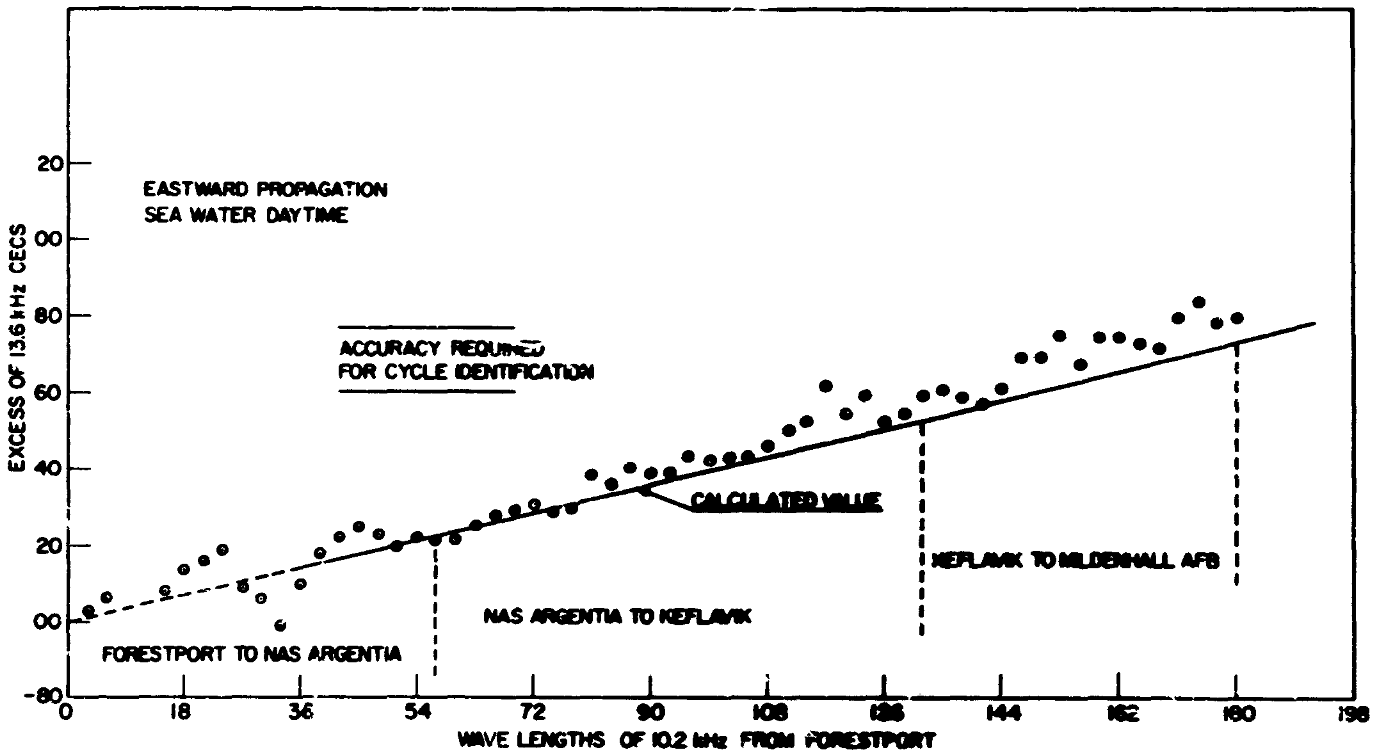


Fig. 2 - Result of velocity difference between 10.2 kH_z and 13.6 kH_z



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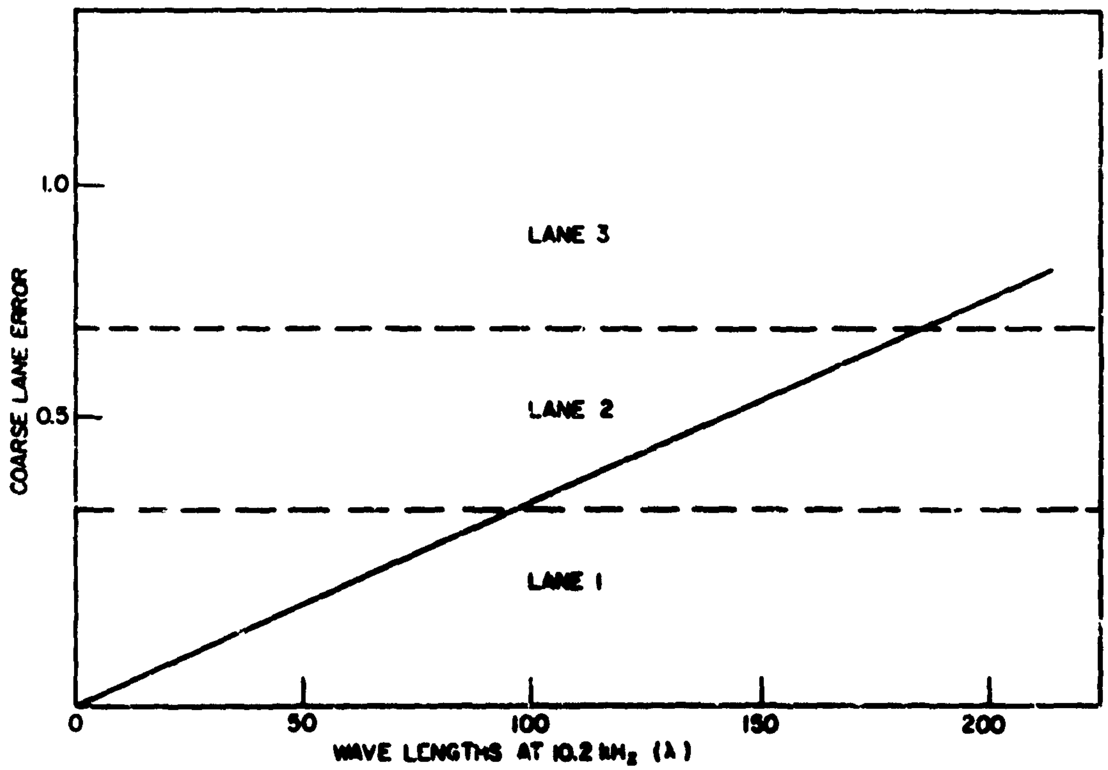

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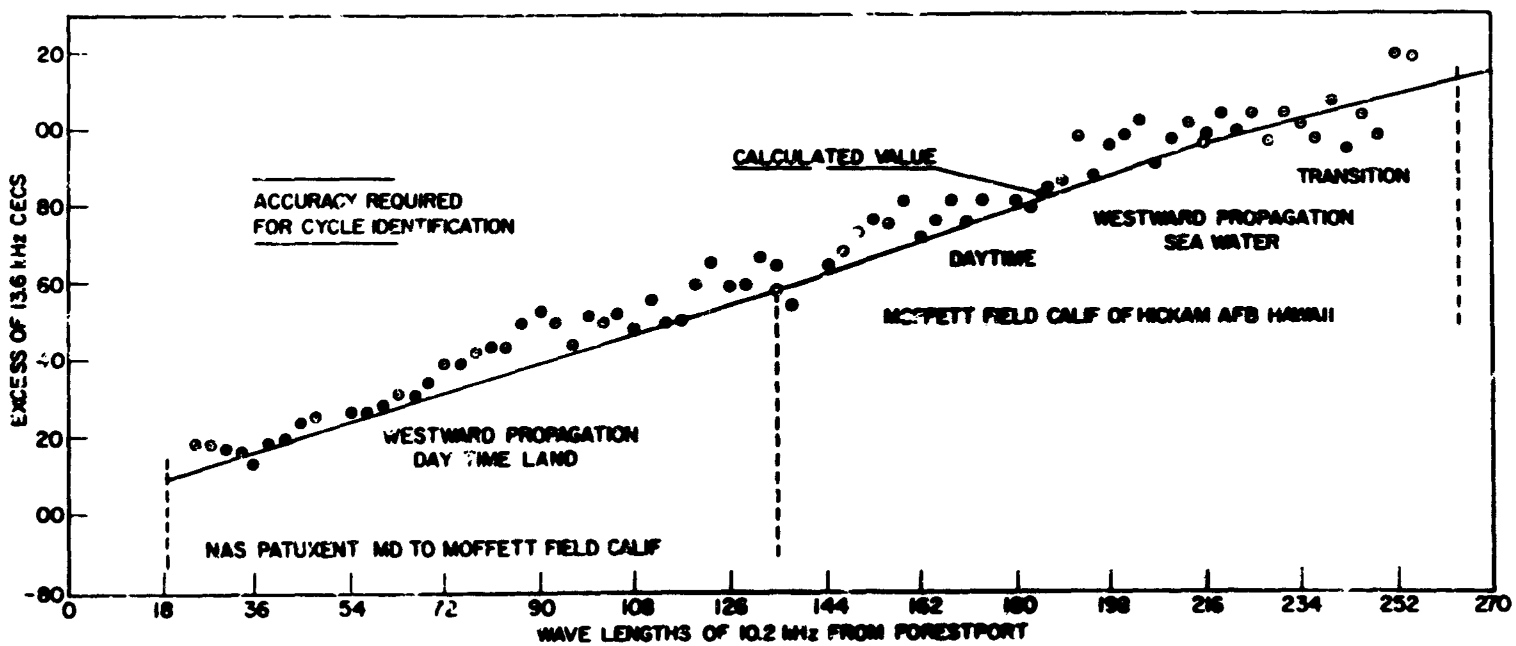

Fig. 5 - Dispersion between 10.2 kH_z and 13.6 kH_z observed on signals from Forestport

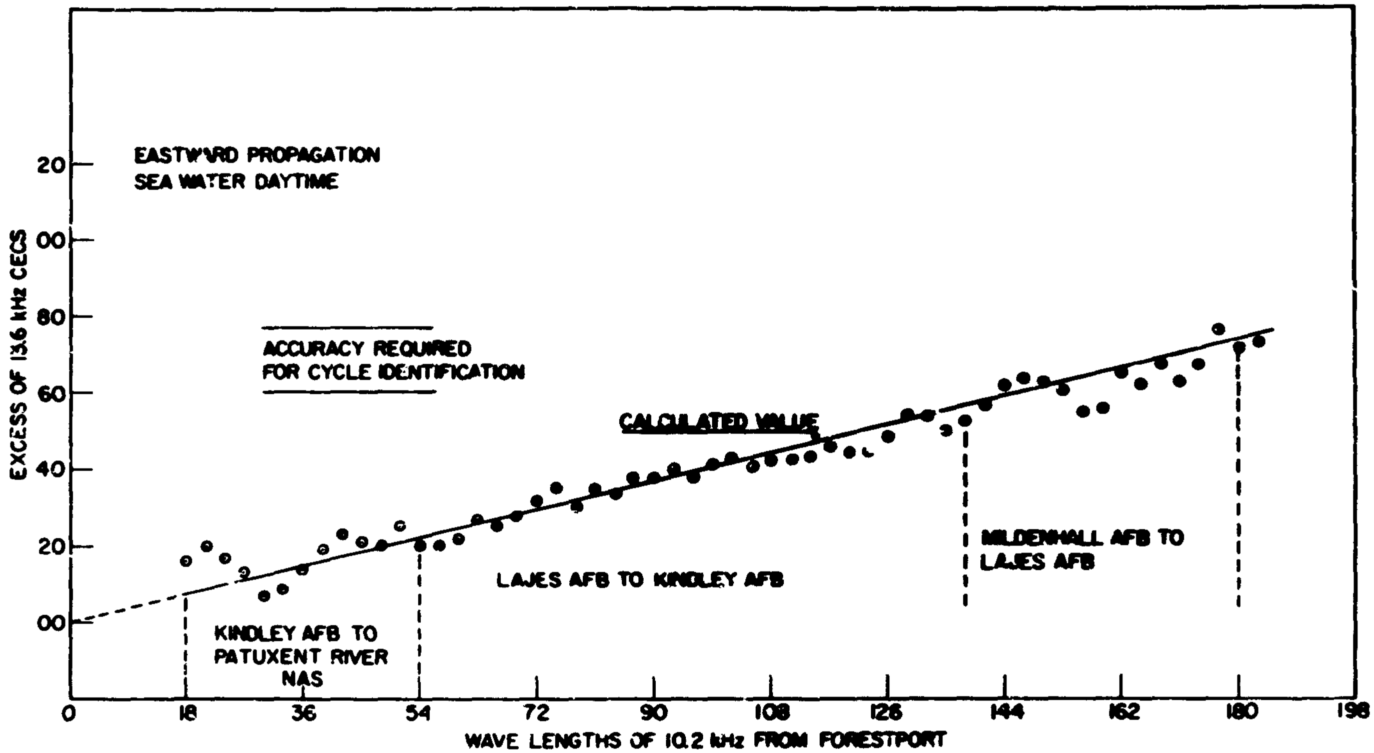

Fig. 4 - Dispersion between 10.2 kH_z and 13.6 kH_z observed on signals from Forestport

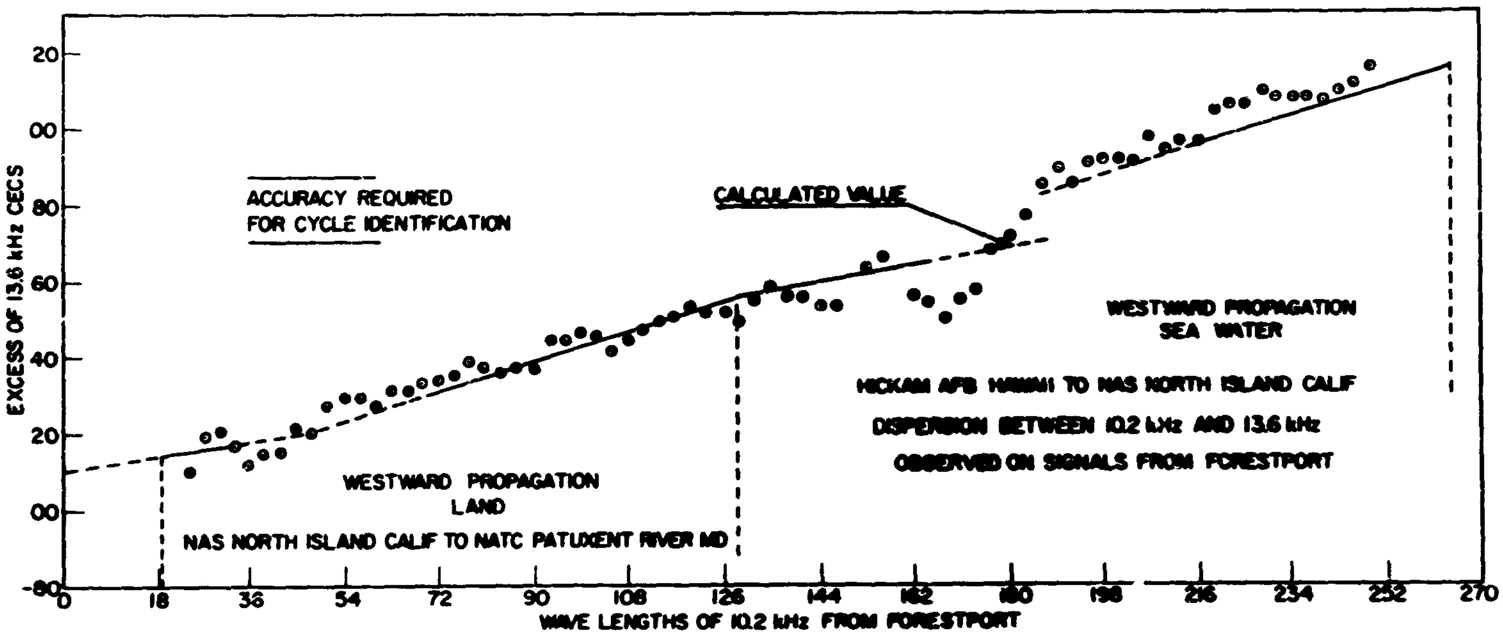

Fig. 7 - Dispersion between 10.2 kH_z and 13.6 kH_z observed on signals from Forestport

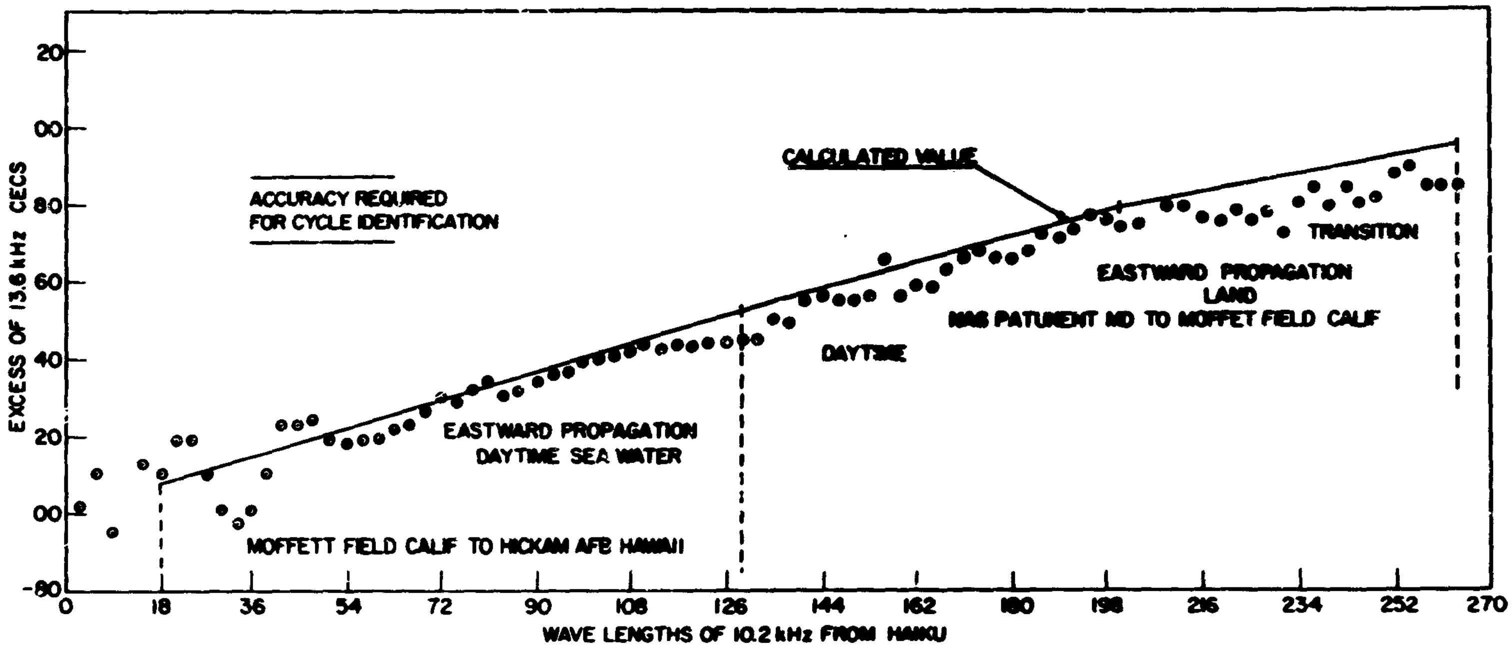

Fig. 6 - Dispersion between 10.2 kH_z and 13.6 kH_z observed on signals from Haiku

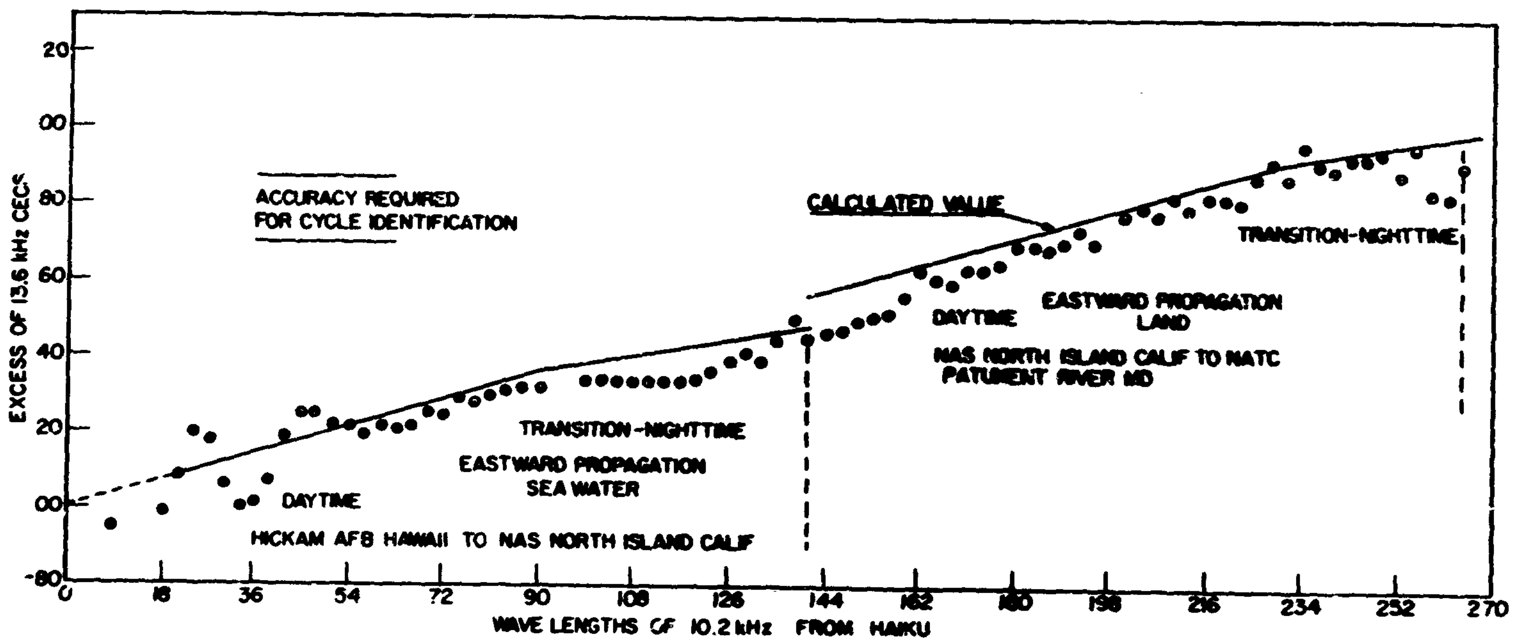

Fig. 8 - Dispersion between 10.2 kH_z and 13.6 kH_z observed on signals from Haiku